Chapter 1 - Introduction

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Chapter 1 - Introduction

1.1 Background

The Virginia Department of Transportation (VDOT) has developed the 2002* VDOT Drainage Manual to provide designers a valuable reference and tool for the drainage design of Virginia's roadways and to document VDOT's policies and procedures for standard roadway drainage design.

This edition of the VDOT Drainage Manual constitutes a major technical update and compilation of the existing VDOT Drainage Manual, the AASHTO Model Drainage Manual, and other resources and has been prepared in electronic format to be made available on the Internet at the VDOT website. VDOT's Hydraulics Section prepared this edition of the manual.

The objectives of the manual are to:

- Provide concise technical information for drainage designers
- Establish VDOT's policies and procedures for drainage design
- Provide an educational tool for aspiring drainage designers and instructors
- Provide in electronic format, available on the World Wide Web for viewing and downloading
- Provide guidelines to enhance the quality of drainage design submittals to VDOT

* Rev 1/17

1.2 Overview

1.2.1 Purpose

This manual is intended as an operational handbook for use in hydrologic and hydraulic analysis. Design concepts, policies and procedures, criteria, and examples are condensed and written for use by the designer. Where appropriate, relevant hydraulic design publications are referenced. While it is essential that the user of this manual is familiar with the methods of analysis and design of highway drainage for VDOT, the text provides detailed instructions and criteria for the development of analysis and design in most cases. An exception to this rule is the case where another source document expounds upon the method in great detail. In this case, the manual directs the user to the source document or provides a brief synopsis of the subject.

This manual is intended for use in the development of VDOT highway drainage design projects by Department staff, consultants, and Virginia's municipalities. Educational organizations may use the manual as instructional text in design application. The manual gives the designer a basic working knowledge of hydrology and hydraulics, illustrated with example problems. Basic design elements are included so that the designer can design highway drainage with minimal assistance. However, this manual cannot provide guidance on complex hydrologic or hydraulic problems and is no substitute for experience, formal training, or engineering judgment.

The Department recognizes the difficulty in accurately defining or predicting the dynamic properties of nature. There are numerous methods of analysis available and it is recommended that as many method(s) as may be appropriate be employed in the solution of a problem. Further, all hydraulic designs must give consideration to economic, aesthetic, and environmental aspects of the given design.

Complete documentation of all analyses is essential and must be perpetually maintained. The rapid development of technology in the fields of hydrology and hydraulics necessitates a periodic review and, if necessary, update of all analyses prior to construction of the facility. All analysis completed more than three years before construction must be reviewed prior to construction.

1.2.2 Manual Layout/Chapter Templates

Typical section headings for the main hydraulic chapters are identified in Table 1-1, which indicates the typical contents of the chapter sections.

The Design Concepts section for each technical chapter is generally based on the AASHTO Model Drainage Manual. As such, the material is included for theoretical background and may not conform exactly to VDOT methodology, terminology, or nomenclature. When practical, the text is revised to be consistent with VDOT methodology and policy.

Table 1-1. Chapter Template and Contents

Sections	Contents
Introduction	Objectives
Policy	Define Course of Action for VDOT, State, Federal and Local Policy
Design Criteria	Specify Standards by which Policy is Carried Out
Design Concepts	Design Considerations/ Guidelines Theory and Equations Requirements Figures Necessary to Support Procedures or Examples
Design Procedures & Examples	Step-by-Step Procedures Specific Design Considerations Specific Software Solutions Figures Necessary to Support Procedures or Examples
References	Sources of Information / Bibliography
Appendices	All Figures, Forms and Design Aids Not Necessary to be in Concepts or Procedures Drainage Design Memoranda Definitions Checklists Symbology and Nomenclature

1.3 Drainage Design Memoranda

Drainage Design Memoranda contain instructional and informational guidance related specifically to drainage design. The instructions and information contained in these memoranda are subject to relatively frequent changes and have therefore intentionally been* excluded from the main body of text in this manual. These memoranda are all contained in Chapter 15. All Technical Supplements, and Drainage Manual Errata Sheets published prior to issuance of this manual are now included in the manual and are hereby voided.

* Rev 7/14

1.4 References

The manual provides references at points where the designer may need more detailed source material. The reference section at the end of each chapter includes these source documents, as well as a listing of those documents, which are recommended additions to the designer's library of references.

The following documents are an integral part of VDOT roadway and drainage design:

VDOT Reference Documents (all latest editions)

- VDOT Road and Bridge Standards, Volume I and II
- VDOT Road and Bridge Specifications
- VDOT Instructional and Informational Memoranda
- VDOT Road Design Manual
- Virginia Stormwater Management Regulations (9VAC25-870)*
- Virginia Erosion and Sediment Control Regulations (9VAC25-840)
- Virginia Erosion and Sediment Control Handbook
- Virginia Stormwater Management Handbook, Volumes I and II
- VDOT Survey Instruction Manual

Compliance with the following applicable laws and agencies' regulations and policies are required:

- Virginia Department of Transportation
- Virginia Stormwater Management Regulations
- Virginia Erosion and Sediment Control Regulations
- State Drainage Law
- FHWA Federal Aid Policy Guide
- Federal Emergency Management Agency
- Environmental Protection Agency Regulation
- National Pollution Discharge Elimination System (NPDES)
- Department of Environmental Quality

* Rev 7/14

1.5 User Instructions

This manual is divided into 16* chapters, each dealing with a major category of hydrologic or hydraulic analysis. Each chapter is further divided according to specific elements of the subject. Departmental policy and design criteria are presented in each chapter as they relate to the specific subject matter.

The downloaded electronic version of the Drainage Manual and its revisions will be considered the official reference document in agreements with consultants. The manual can be downloaded from VDOT's website at the following location: http://www.virginiadot.org/business/locdes/hydra-drainage-manual.asp. The authors of this manual have strived to maintain the accuracy and reliability of the information and procedures presented herein. The execution of an engineering design; however, involves the judgment of the designer, and only he or she can ascertain whether a technique or item of information can be applied to a given situation. Therefore, neither the Department nor any contributor accepts responsibility for any real or alleged error, loss, damage, or injury resulting from use of the material contained herein.

References to specific computer programs, AASHTO guidelines, manual, and regulations are included in this manual. It is expected that the designer will be knowledgeable in the use of the referenced items. This manual cannot incorporate computer program user manuals or remain current with these programs and the latest drainage-related Federal regulations. The designers should keep themselves up-to-date by contacting either their local, State, or Federal hydrology/hydraulic departments.

This manual is published in U. S. Customary (English) units. In most cases all units, equations, tables, and figures are given in English units. In a few instances, some existing metric information was not converted to English units. The metric units are given so that the material could still be included in the manual. In most cases, computer software is available that allows the use of English units that can be used to obtain the required information.

Information in this Manual may be supplemented and/or revised by drainage related Location and Design Instructional and Informational Memorandums (IIM's). Information in these IIM's shall supersede that noted in this Manual unless otherwise approved by the State Hydraulics and Utilities Engineer. Where language in various sections of this Manual conflict, the more stringent language shall dictate unless otherwise approved by the State Hydraulics and Utilities Engineer.

* Rev 7/14

1.6 Revisions and Updates

VDOT plans to issue updates and revisions to this manual which will be found at the VDOT website. Updates and revisions would normally be anticipated no more than twice a year. Users of the manual should review the VDOT website periodically and prior to beginning design or preparing a plan submittal, to determine the date of the most recent updates. Users that cannot access the information on the Internet may phone the VDOT Hydraulics Section in the nearest district office or Central Office in Richmond, Virginia. When revisions are available, the user will be notified via an Errata Sheet file on the VDOT website at the location where the manual may be viewed and/or downloaded. These files also briefly describe each revision. All revised material (where possible) will be shaded so the user will be able to recognize it as having been changed. The shaded material within any given chapter will remain shaded until the next revision, at which time all previous shading in that chapter will be removed.

1.7 Acknowledgements

The Department gratefully acknowledges the following for their contribution towards the preparation of this Manual:

- American Association of State Highway and Transportation Officials (AASHTO Drainage Manual, Highway Drainage Guidelines, and other publications)
  - Executive Committee
  - Hydrology and Hydraulics Technical Committee
- Federal Highway Administration
- Federal Emergency Management Agency
- United States Geological Survey
- United States Army Corps of Engineers
- Virginia Department of Transportation –
  - Mr. Jeff Bragdon, P.E., State Hydraulics and Utilities Engineer
  - Mr. Chris Swanson, P.E., State MS4/Stormwater Management Engineer*
  - Mr. Roy Mills, Former State Hydraulics Engineer and Member AASHTO Hydrology and Hydraulics Technical Committee
- Virginia Department of Conservation and Recreation – Division of Soil & Water Conservation
- Virginia Department of Environmental Quality
- Materials furnished by other state and federal agencies
- Research publications and materials furnished by the private sector
- Photo on cover courtesy of Virginia Department of Game and Inland Fisheries. Photographed by Mr. Dwight Dyke. Big Tumbling Creek at the Clinch Mountain Wildlife Management Area.

The Department's Hydraulic Section wishes to express its appreciation to all contributors who assisted in the development of this manual.

*Rev 1/17

Appendix 1A-1 Abbreviations and Definitions

Abbreviations:

AASHTO	American Association of State Highway and Transportation Officials
BDF	Basin Development Factor
BLM	Bureau of Land Management
BMP	Best Management Practice*
BRI-STARS	Bridge Stream Tube Model for Sediment Routing Alluvial River Simulation
BSD	Better Site Design
CBPA	Chesapeake Bay Preservation Area
CEM	Coastal Engineering Manual
CF	Channel Flow
CFR	Code of Federal Regulations
DCR	Department of Conservation and Recreation
DDM	Drainage Design Memorandum
DEQ	Department of Environmental Quality
EO	Executive Orders
EPA	Environmental Protection Agency
ESC	Erosion and Sediment Control
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FWPCA	Federal Water Pollution Control Act
FWS	Fish and Wildlife Service
HDS	Hydraulic Design Series
HEC	Hydraulic Engineering Circular
HIRE	Highways in the River Environment
HUC	Hydrologic Unit Code
HW	Headwater
HYG	Hydrograph
I&IM or IIM	Instructional and Informational Memorandum
IDF	Intensity Duration Frequency
LDP	Land Development Project
LID	Low Impact Development
LTEC	Least Total Expected Cost
MHW	Mean High Water
MHHW	Mean Higher High Water
MLW	Mean Low Water
MLLW	Mean Lower Low Water
MS	Minimum Standard
MS4	Municipal Separate Storm Sewer System
MSL	Mean Sea Level
MTL	Mean Tide Level

* Rev 9/09

MTR	Mean Tide Range
NAS	National Academy of Sciences
NAVD	North America Vertical Datum
NEH	National Engineering Handbook
NEPA	National Environmental Protection Agency
NFIA	National Flood Insurance Act
NFIP	National Flood Insurance Program
NGS	National Geodetic Survey
NGVD	National Geodetic Vertical Datum
NHS	National Highway System
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	National Resource Conservation Service (formally known as the Soil Conservation Service or SCS)
NTIS	National Technical Information Service
OLF	Overland Flow
PAC	Pre-Advertisement Conference
P2	Pollution Prevention
R&B	Road and Bridge
RDM	Road Design Manual
RFP	Request for Proposal
R/W	Right-of-Way
SCS	Soil Conservation Service (former name of the National Resource Conservation Service)
SPM	Shore Protection Manual
SWCB	Soil and Water Conservation Board
SWL	Still Water Level
SWM	Stormwater Management
SWMR	Stormwater Management Regulations
SWPPP	Stormwater Pollution Prevention Plan
SYIP	Six-Year Improvement Plan
TMDL	Total Maximum Daily Load
TR	Technical Release
TVA	Tennessee Valley Authority
TW	Tailwater
USBR	United States Bureau of Reclamation
USCOE/USACE	United States Corps of Engineers
USGS	United States Geological Survey
VAC	Virginia Administrative Code
VDOT	Virginia Department of Transportation or the “Department”
VESC	Virginia Erosion and Sediment Control
VESCH	Virginia Erosion and Sediment Control Handbook
VESCR	Virginia Erosion and Sediment Control Regulations
VPDES	Virginia Pollutant Discharge Elimination System
VRRM	Virginia Runoff Reduction Methodology
VSMP	Virginia Stormwater Management Program

VSMR	Virginia Stormwater Management Regulations
VSWCB	Virginia Soil and Water Conservation Board
WES	Waterways Experiment Station
WQV	Water Quality Volume
WRC	Water Resources Council

Definitions:

Adequate Channel	(1) A natural channel, which is capable of conveying the runoff from a 2-year storm without overtopping its banks or eroding after development of the site in question, (2) A previously constructed man-made channel shall be capable of conveying the runoff from a 10-year storm without overtopping its banks, and bed or bank erosion shall not occur due to a 2-year storm, (3) Pipes and storm sewer systems shall contain the 10-year storm.
Average Land Cover Condition	A measure (in percent) of the average amount of impervious area within a watershed.
Backshore	The backshore is the area of the coastal zone that extends from the limit of high tides and storm waves to the base of a cliff or beach ridge.
Barrier Beach	A bar essentially parallel to the shore, which has been built up so that its crest rises above the normal high water level.
Bridges	(1) Structures that transport traffic over waterways or other obstructions, (2) Part of a stream crossing system that includes the approach roadway over the floodplain, relief openings, and the bridge structure, (3) Structures with a centerline span of 20 feet or more; however, structures designed hydraulically as bridges are considered bridges, regardless of length.
CBR Tests	The California Bearing Ratio (CBR) test consists of measuring the relative load required to cause a standard (3 square inches) plunger to penetrate a water-saturated soil specimen at a specific depth.
Channel	A natural or manmade waterway (includes culverts and storm sewer systems).
Check Storm	The use of a less frequent event, such as a 50-year storm, to assess hazards at critical

	locations, where water can pond to appreciable depths.
Code of Federal Regulations	Codifies and publishes at least annually Federal regulations currently in force. The CFR is kept up to date by individual issues of the *Federal Register.* The two publications must be used together to determine the latest version of any given rule.
Common Enemy Doctrine	Common law rule recognized by some states, pertaining to the disposal of surplus or excess surface waters, which holds that such waters are a "common enemy"; therefore, the land owner has the right to protect his lands from such waters coming from higher lands. Under this rule, surface waters are regarded as a common enemy, which each landowner may fight as he deems best and without regard to the harm that may be caused to others.
Common Laws	The body of principles which developed from immemorial usage and custom and which receives judicial recognition and sanction through repeated application.
Critical Depth	Critical depth is the depth at which the specific energy of a given flow rate is at a minimum. For a given discharge and cross-section geometry there is only one critical depth.
Culvert	(1) A structure which is usually designed hydraulically to take advantage of submergence to increase hydraulic capacity, (2) A structure used to convey surface runoff through embankments, (3) A structure, as distinguished from bridges, which is usually covered with embankment and is composed of structural material around the entire perimeter, although some are supported on spread footings with the streambed serving as the bottom of the culvert, (4) A structure which is traditionally 20 feet or less in centerline length between extreme ends of openings for multiple boxes; however, a structure designed

	hydraulically as a culvert is treated as a culvert, regardless of length.
Deep-water Wave	A wave in which the depth of water is greater than one-half the wavelength.
Department	The Virginia Department of Transportation.
Detention Basins	A basin or reservoir incorporated into the watershed, whereby runoff is temporarily stored, thus attenuating the peak of the runoff hydrograph. A stormwater management facility that impounds runoff and temporarily impounds runoff and discharges it through a hydraulic outlet structure to a downstream conveyance structure.
Discharge Point	The location at which stormwater and/or a pollutant leaves the project area.
Downcast	The direction of predominant movement of littoral currents and transport.
Embayment	An indentation in a shoreline forming an open bay.
English Rule	Based on the doctrine of absolute ownership of water beneath the property by the landowner. The English Rule is analogous to the common enemy rule in surface water law.
Eutrophication	The process of over-enrichment of water bodies by nutrients often typified by the presence of algal blooms.
Executive Orders	Federal laws that are issued by the President of the United States.
Federal Register	A daily publication of the Federal Government making federal regulations, legal notices, Presidential Proclamations, Executive Orders, etc., known to the public as they are proposed and subsequently issued.
Fetch	The length of unobstructed open sea surface across which the wind can generate waves.

Flood Insurance Study	Established the original floodway.
Flow Type	The USGS has established seven culvert flow types which assist in determining the flow conditions at a particular culvert site.
Foreshore	The foreshore is the area of the coastal zone that extends from the low-tide level to the limit of high tides and storm-wave effects.
Free Outlet	A free outlet has a tailwater equal to or lower than critical depth. For culverts having free outlets, lowering of the tailwater has no effect on the discharge or the backwater profile upstream of the tailwater.
Headland	A headland is the seaward most projection of land from the shoreline. Because headlands project out into waves and currents, headlands are usually subjected to greater erosion forces. Headlands may be the remnants of submerged ridgelines or be composed or erosion resistant materials.
HUC6	A watershed unit established in the most recent version of Virginia's 6th Order National Watershed Boundary Dataset.
Hydraulic Grade Line	The elevation to which the water can be expected to rise within a storm drain (pressure head + elevation head)
Impervious Surface or Cover	A surface composed of any material that significantly impedes or prevents natural infiltration of water into soil. Impervious surfaces include, but are not limited to, roofs, buildings, streets, parking areas, and any concrete, asphalt, or compacted gravel surface.
Impervious Area	The area (square feet or acres) of the site composed of an impervious surface.
Improved Inlet	An improved inlet has an entrance geometry, which contracts the flow as it enters the barrel thus increasing the capacity of culvert. These

	inlets are referred to as either side- or slope-tapered (walls or walls and bottom tapered).
Karst Topography	Irregular topography characterized by sinkholes, stream-less valleys and streams that disappear into the underground, all developed by the action of surface and underground water in soluble rock such as limestone.
Lakeshore	The strip of land from a lake shoreline inland to the first major change in terrain features. Except for tidal effects, large lakes and reservoirs of 100 mi^2 or more in area, have shores that require many of the same type considerations as ocean bays and estuaries. Analogous to coastal zone tides, some lakeshores are subject to significant changes in water surface elevation due to operation practices.
Land-Disturbing Activity or Land Disturbance	A manmade change to the land surface that potentially changes its runoff characteristics including any associated clearing, grading or excavation.
Linear Development Projects	Those land-disturbing activities linear in nature such as, but not limited to, highway construction/ maintenance projects/ activities, construction/ maintenance of stormwater channels and stream restoration projects.
Longshore	Currents or sediment transport that move parallel to the shoreline.
Managed Turf	Means portions of roadway rights-of-way that are pervious and do not meet the definition of open space.
Mean Higher High Water (MHHW)	MHHW is the average tidal elevation of the highest tidal elevation in a tidal day experienced over the 19-year metonic cycle.

Mean High Water (MHW)	MHW is the average high water elevation (both Higher High Water and Lower High Water) experienced over the 19-year metonic cycle.
Mean Lower Low Water (MLLW)	MLLW is the is the average tidal elevation of the lowest tidal elevation in a tidal day experienced over the 19-year metonic cycle.
Mean Low Water (MLW)	Tidal elevations and the vertical datums of coastal bathymetric maps are often referenced to Mean Low Water (MLW). MLW is the average low water elevation (both Lower Low Water and Higher Low Water) experienced over the 19-year metonic cycle.
Metonic Cycle	The Metonic cycle is a period of 19 years in which there are 235 lunations, or synodic months, after which the Moon's phases recur on the same days of the solar year, or year of the seasons.
MS4 General Permit	General Permit for Discharges of Stormwater from Small Municipal Separate Storm Sewer Systems.
Non-Linear Projects	Those land-disturbing activities not considered linear in nature such as, but not limited to, parking lots, rest areas and District/Residency/ Area Headquarter complexes.
Normal Flow	Normal flow occurs in a channel reach when the discharge, velocity and depth of flow do not change throughout the reach. The water surface and channel bottom will be parallel. This type of flow will exist in a culvert operating on a constant slope provided the culvert is sufficiently long.
Offsite	Areas located outside of the VDOT right of way, easement or property boundary.
Onsite	Areas located inside of VDOT right of way, easement or property boundary.
Open Space	Means portions of roadway rights-of-way and permanent easements associated with a land-disturbing activity that, following construction,

	have either not been compacted by the activity; have had soil restoration; or have placed engineered soil mix, and will not be actively maintained. Typically, actively maintained means mowed more than four (4) times a year or fertilized. Surfaced area of stormwater facilities, with the exception of wet ponds, shall qualify as open space.
Outfall	The location where concentrated stormwater leaves the project area.
Pre-development	Those conditions that exist prior to commencement of the proposed land-disturbing activity/project.
Pre-development Impervious Area	The amount of impervious area within the site prior to commencement of the proposed land-disturbing activity/project.
Pre-development Percent Impervious	The amount of pre-development impervious area within the site divided by the total area of the site times 100.
Post-development	Those conditions that will, or are expected to, exist after completion of the proposed land-disturbing activity/project.
Post-development Impervious Area	The amount of impervious area within the site that will or is expected to exist after completion of the proposed land-disturbing activity/project.
Post-development Percent Impervious	The amount of post-development impervious area within the site divided by the total area of the site times 100.
Q_1 Control	This stormwater management measure is applied to channels with known or anticipated erosion problems as a quantity control measure. In design, the entire contributing drainage area to the proposed basin is

	captured and used to develop the detention volume for a 1-year storm.
Reasonable Use Rule	States in essence that each landowner is restricted to a reasonable exercise of his own right and a reasonable use of his property in view of the similar right of his neighbors.
Receiving Channel	The drainage facility that receives the stormwater run-off from the proposed land-disturbing activity.
Redevelopment	Means development on prior developed lands that have been previously utilized for residential, commercial, industrial, institutional, recreation, transportation or utility facilities or structures and that will have the impervious areas associated with those uses altered during a land-disturbing activity.
Regulated Land Disturbance Activities	Those activities that disturb one (1) acre or greater except in those areas designated as a Chesapeake Bay Preservation Area in which case the land disturbance threshold is 2500 square feet or greater (unless the activity is specifically exempted by the VSMP Law and/or Regulations).
Regulated Site	The area within the project limits used to determine water quality requirements.
Retention Basins	A basin or reservoir wherein water is stored for regulating a flood. It does not have an uncontrolled outlet. The stored water is disposed by such means as infiltration, injection (or dry) wells, or by release to the downstream drainage system after the storm event. The release may be through a gatecontrolled gravity system or by pumping
Riparian Doctrine	A doctrine that holds that the property owner adjacent to a surface water body has first right to withdraw and use the water. This doctrine may be set aside by a state's statutory law that

holds that all surface waters are the property of the state.

Roadway Section — The traveled way and associated shoulders, ditches, sidewalks, multi-use/shared use paths, back (cut) slopes and fore (fill) slopes

Seiche — A seiche is an oscillatory wave generated by an impulse that disturbs the local water level equilibrium. The impulse may be a heavy rainfall, vessel passage, tsunami, flood discharge from a river, or a storm surge. Much like dropping a stone in to a tank of water, seiche waves oscillate back and forth, gradually diminishing in magnitude.

Site — The area of proposed land disturbance (e.g., the construction limits) plus any R/W acquired in support of the proposed land disturbance activity/project. Any support areas within existing or proposed VDOT R/W associated with the proposed land disturbance activity/project and identified in the pre-construction SWPPP for the proposed land disturbance activity/project shall also be considered a part of the site. Permanent easements and/or other property acquired through the R/W acquisition process in conjunction with the proposed land disturbance activity/project may be considered a part of the site and utilized in the determination of the post-development water quality requirements provided such property will remain under the ownership/control of the VDOT and providing such property is so identified/designated on the proposed land disturbance activity/project plans and is legally encumbered for the purpose of stormwater management.

Slope — A steep slope occurs where critical depth is greater than normal depth. A mild slope occurs where critical depth is less than normal depth.

Spread — The width of flow measured laterally from the flowline. With a curbed only section of

	roadway, the flowline is formed by the intersection of the pavement to the curb. With a curb and gutter section, it is the intersection of the gutter pan and the curb.
Statutory Laws	Enacted by legislatures to enlarge, modify, clarify, or change the common law applicable to particular drainage conditions. This type of law is derived from constitutions, statutes, ordinances, and codes.
Still-water Level (SWL)	SWL is used to refer to the imaginary elevation of water if all wave and wind action were to cease. SWL is used to define limits of coastal inundation during storm surges. Actual water levels are higher due to waves.
Storm Drain	A storm drain system is a drainage system installed to carry stormwater runoff, consisting of two or more pipes in a series connected by one or more drop inlets. An exception to this general rule is: one or more cross drain pipes connected by one or more drop inlets, "hydraulically designed" to function as a culvert(s) and not connected to a storm drain system.
Stormwater Conveyance System	A combination of drainage components that are used to convey stormwater discharge, either within or downstream of the land-disturbing activity.
Submerged	A submerged outlet occurs when the tailwater elevation is higher than the crown of the culvert. A submerged inlet occurs when the headwater is greater than 1.2D where D is the culvert diameter or barrel height.
Surf Zone	The area where deep-water waves break (collapse) forming breakers. Note that on shallow sloped shorelines, waves may reform and more than one surf zone may be present.
Tort	A violation of a personal right guaranteed to the individual by law.

Traveled Way or Travel Lane	That portion of the roadway section, exclusive of shoulders, designated for vehicular use.
Velocity Head	A quantity of energy head proportional to kinetic energy of flowing water.
Watershed	The surface area, measured in a horizontal plane, draining to a specific point in a channel, stream, river or other such watercourse. Also often referred to as “Drainage Area” or “Drainage Basin”.

Appendix 1A-2 Symbols

Symbol	Definition	Units
A	Drainage Area	acres, mi^2
A	Cross-sectional area of flow; Clear opening area of curb inlet or grate; Cross-sectional or surface area	ft^2
a	Rainfall regression constant	-
a	Depth of depression	feet
B	Barrel or box width	inches, feet
b	Manhole diameter or width	feet
b	Rainfall regression constant	-
b1	Urban Regression Method exponent	-
b2	Urban Regression Method exponent	-
b3	Urban Regression Method exponent	-
b4	Urban Regression Method exponent	-
b5	Urban Regression Method exponent	-
b6	Urban Regression Method exponent	-
b7	Urban Regression Method exponent	-
BDF	Basin Development Factor	%

Appendix 1A-2 Symbols

C	Runoff coefficient; Urban Regression Method constant; Stone size correction factor; Broad-crested weir coefficient or orifice coefficient	-
C_d	Overtopping coefficient (Weir coefficient)	-
C_f	Frequency factor	-
CN	SCS-runoff curve number	-
C_r	Discharge coefficient	-
C_{SF}	Adjustment to the stability factor	-
C_{sg}	Adjustment to the specific gravity of stone	-
C_t, C_p	Physiographic coefficients	-
C_W	Weir coefficient	-
D	Culvert diameter or barrel height; Diameter of pipe	inches, feet
d	Depth of flow; Depth of gutter flow at the curb line; Change in elevation; Orifice diameter	feet
D_{50}	Mean spherical diameter of the 50% size stone	feet
D_{50s}	Required D_{50} for side slopes	feet
d_{50}	Mean stone size diameter	inches, feet
d_{avg}	Average flow depth in the main channel	feet
d_B	Critical depth at riprap basin overflow	feet

Appendix 1A-2 Symbols

d_c	Critical depth	feet
D_e	Storm duration	minutes
d_E	Equivalent brink depth	feet
d_i	Depth at lip of curb opening	feet
D_m	Mean depth of lake or reservoir	feet
d_n or d_o	Normal depth	feet
d_s	Maximum water depth at toe of rock slope protection or bar	feet
E	Specific energy	feet
E	Curb opening efficiency	-
E_o	Ratio of depression flow to total gutter flow	-
F_r	Froude Number	-
G	Coefficient of Skew	feet
g	Acceleration due to gravity	ft/s^2
H	Total head loss; Head loss; Depth of water; Wave height	feet
h	Stage or head; Height of curb opening inlet; Head	feet

Appendix 1A-2 Symbols

h_{Δ}	Bend head loss	feet
H_1	Average design wave height for highest 1%	feet
H_{10}	Average design wave height for highest 10%	feet
h_{avg}	Average head	feet
H_b	Bend head loss; Design wave height	feet
H_D	Average hydraulic depth	feet
h_e or H_E	Entrance head loss	feet
h_f or H_f	Friction loss; Friction head loss	feet
H_g	Grate losses	feet
HGL_{ds}	Elevation of the hydraulic grade line at downstream node	feet
HGL_{us}	Elevation of the hydraulic grade line at upstream node	feet
H_j	Junction losses	feet
h_L	Total head loss due to local minor and friction losses	feet
H_L	Total energy losses	feet
h_m	Minor head loss	feet
h_{max}	Maximum head	feet

H_o	Outlet or exit losses	feet
h_o	Hydraulic grade line height above outlet invert; Exit head loss; Summation of minor losses	feet
h_s	Depth of riprap basin	feet
H_s	Significant (design) wave height	feet
H_v	Velocity head	feet
HW	Headwater depth (subscript indicates section)	feet
HW_i	Headwater depth as a function of inlet control	feet
HW_o	Headwater depth above outlet invert	feet
HW_{oi}	Headwater depth as a function of outlet control	feet
HW_r	Headwater depth above roadway	feet
I	Inflow rate	cfs
i	Average Rainfall intensity; Rainfall intensity	in/hr
I_1	Inflow rate at time 1	cfs
I_2	Inflow rate at time 2	cfs
IA	Percentage of impervious area	%

Appendix 1A-2 Symbols

I_a	Initial abstraction from total rainfall	inches
K	Channel conveyance; Statistical Method Frequency Factor; Anderson Method Coefficient of Imperviousness; Bend loss coefficient; Entrance loss coefficient; Exit loss coefficient	-
K	Conveyance of cross section	cfs
K_e	Entrance loss coefficient	-
K_o	Initial head loss coefficient	-
K_o	Conveyance of the gutter section beyond depression	cfs
k_t	Submergence coefficient	-
K_w	Conveyance of the depressed gutter section	cfs
L	Discharge-weighted or conveyance reach length; Length of culvert; Length of roadway crest; Flow Length or Length of Strip; Anderson Method Basin Length or Snyder Method Channel Length; Length of grate inlet; Length of curb opening; Length of pipe; Broad-crested weir length	feet
l	Length of mainstream to furthest divide	feet
L’	Equivalent length of channel	miles
L_B	Length of riprap basin	feet
L_{ca}	Length along main channel to a point opposite the watershed centroid	miles

Appendix 1A-2 Symbols

L_R	Require length of inlet	feet
L_s	Length of dissipating pool	feet
L_T	Curb opening length for 100% interception	feet
M	Rank of a flood within a long record	-
m	Number of flow segments	-
N	Number of years of flood record	years
n	Manning's roughness coefficient	-
O_1	Outflow rate at time 1	cfs
O_2	Outflow rate at time 2	cfs
P	Precipitation	inches
P and P_w	Wetted perimeter; Perimeter of grate opening	feet
Q	Statistical Method Mean of Logs	-
Q	Discharge; Total flow to inlet or flow in gutter	cfs
Q	SCS Direct Runoff	inches
q	Storm runoff during a time interval	inches
Q, Q_p	Maximum rate of runoff or Peak Discharge; Discharge or flow rate	cfs

Appendix 1A-2 Symbols

Q_{avg}	Average flow rate	cfs
Q_b	Bypass flow	cfs
Q_d	Discharge through the culvert	cfs
Q_i	Peak inflow rate	cfs
Q_L	Mean of the logarithms of the peak annual floods	cfs
Q_o	Peak outflow rate	cfs
q_o	Allowable outflow rate	cfs
Q_s	Gutter capacity above the depressed section	cfs
Q_t	Design or check discharge at culvert	cfs
Q_T	Total flow	cfs
Q_t	Maximum allowable flow	cfs
Q_w	Flow in width W	cfs
R	Flood frequency ratio	-
R	Hydraulic radius (A/P)	feet
RC	Regression constant	-

Appendix 1A-2 Symbols

R_f	Ratio of frontal flow intercepted to total flow	-
RI2	Rainfall intensity for the 2-hr, 2-yr occurrence	inches
RQ	Equivalent rural peak runoff rate	cfs
RQ_T	Rural Regression for Return Period T Peak Discharge	cfs
R_s	Ratio of side flow intercepted to total flow	-
S	Anderson Method Index of Basin Slope	ft/mi
S	SCS Method Potential maximum retention storage	inches
S	Slope of the energy grade line; Longitudinal slope of pavement or gutter slope	ft/ft
S	Storage volume	ft^3, ac-ft.
S or Y	Ground slope	ft/ft or %
S_1	Storage volume at time 1	ft^3
S_2	Storage volume at time 2	ft^3
S_A	Average slope of the energy grade line	ft/ft
S_e	Equivalent cross slope	ft/ft
SF	Stability factor applied	-
S_f	Friction slope	ft/ft

Appendix 1A-2 Symbols

S_g	Specific gravity of rock riprap	-
Sg_r	Specific gravity of stone	-
Sg_w	Specific gravity of water	-
SL	Urban Regression Method Main Channel Slope	ft/mi
S_L	Standard Deviation	-
S_o	Channel slope; Slope of Culvert	ft/ft
SP	Storage parameter (Pagan Method)	-
ST	Basin storage factor	%
STO	Maximum storage volume (Pagan Method)	-
S_w	Depression section slope or gutter cross slope; Gutter cross slope including local depression	ft/ft
S_x	Cross Slope	ft/ft
Δt	Routing time period (timestep)	seconds
T	Anderson Method Lag Time	hours
T	Top width at the water surface; Spread	feet
T_b, t_b	Time base on hydrograph	hours, minutes

Appendix 1A-2 Symbols

T_c, t_c	Time of concentration; Modified Critical Storm Duration	minutes
T_d	Critical storm duration	minutes
T_i	Duration of basin inflow	hours, minutes
τ_{max}	Maximum tractive force	lbs/ft^2
τ_o	Average tractive force	lbs/ft^2
T_p	Time to Peak	minutes
τ_p	Permissible shear stress	lbs/ft^2
T_r	Time to Recede	minutes
τ_s	Side slope shear stress	lbs/ft^2
T_s	Spread over depressed section	feet
T_t	Travel time	hours
TW	Tailwater depth above invert of culvert	feet
UQ	Urban Regression Method peak runoff rate	cfs
UQ_T	Peak runoff rate for Urban Watershed for Return Period T	cfs
V	Mean velocity; Average velocity of flow; Velocity of flow in gutter	fps
V	Storage volume	

		ft^3, ac-ft.
V_a	Average velocity in main channel	fps
V_B	Average velocity at riprap basin overflow	fps
V_{ce}	Channel erosion control volume	ft^3, ac-ft.
V_d	Average velocity in downstream channel	fps
V_L	Average velocity at length (L) downstream from brink	fps
V_o	Average velocity of flow at culvert outlet; Gutter velocity where splash-over first occurs	fps
V_s	Storage volume estimate	ft^3, ac-ft.
V_u	Average velocity in upstream channel	fps
V_w	Wave velocity	fps
W	Drainage area width; Width of depression; Width of gutter pan; Width of grate	feet
W	Minimum weight of outside stones for no damage	tons
W_{50}	Weight of the 50% size stone	lbs.
W_B	Width of riprap basin at overflow	feet
W_o	Width dimension of culvert shape	feet
WQV	Water quality volume	ft^3

Appendix 1A-2 Symbols

X	Logarithm of the annual peak	-
y	Depth of flow in approach gutter	feet
Z	T/d, reciprocal of the cross slope	-
z	Elevation head	feet
α	Velocity distribution coefficient	-
α	Angle of face slope from the horizontal	degrees
θ	Side slope angle; Angle with respect to centerline of outlet pipe; Angle of embankment with respect to the horizontal	degrees
ρ	70˚ for randomly placed rubble	degrees
ϕ	Angle of repose of material	degrees
γ	Unit weight of water	lbs/ft^3